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TO: Dr. D. Mills
Director of Research

THE EFFECT OF DISTRIBUTION TRANSFORMER LOCATION ON STREET LEVEL MAGNETIC FIELDS AND RESIDENTIAL GROUND CURRENTS

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Measurements have been made of ground-level magnetic fields and house grounding currents in the vicinity of a residential distribution circuit before and after the relocation of a pole-mounted distribution transformer. Because of some public concerns about living next to a distribution transformer, the data were checked for evidence of an association between elevated residential magnetic fields and close proximity to the transformer. For the site tested, no such association was found.

1. INTRODUCTION

Ontario Hydro has received many calls from homeowners who live next to distribution transformers and who are concerned about the effect of the transformers on their own or their children's health. The underlying rationale for these concerns appears to be that the power-frequency magnetic field is likely to be higher in homes nearest to the transformers.

A relation between proximity to a distribution transformer and higher residential magnetic fields was first suggested in a paper reporting on an epidemiological survey of childhood cancer in Denver/1/. In that paper, homes less than 40 m from any number of "large-gauge" overhead distribution primary conductors or six or more "thin" primary conductors, homes less than 20 m from three or more "thin" primaries, and homes less than 15 m from "first-span" secondaries feeding more than two houses, were considered to be in a high magnetic field category. "Large-gauge" primaries and "thin" primaries were differentiated by being larger than and smaller than the secondary (120/240 V) conductors respectively. "First-span" secondaries were secondary conductors located between the distribution step-down transformer and the first residential service drop not connected to the transformer pole. The first-span category was included because the residential load currents flowing in the secondary conductors are expected to be highest next to the transformer.

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The assumed association between transformer location and magnetic fields produced in nearby homes, does not appear to have been tested in any direct way. Consequently, when a municipal utility recently reported plans to move a residential pole-mounted distribution transformer to a different location, arrangements were made to measure magnetic fields and currents along the street both before and after the move. The results are presented in this report.

2. SOURCES OF RESIDENTIAL MAGNETIC FIELDS

Power-frequency magnetic fields in and around a home are caused by 60-Hz currents flowing in metallic conductors inside or outside the house. Inside conductors include household wiring, plumbing, and electrical appliances. Outside conductors include the neighbourhood electrical distribution system, nearby transmission lines (if present), TV and telephone cables, and municipal water mains. Outside and inside conductors are linked by the residential service connections, including electrical service drop wires, the sheaths of TV and telephone cables, and water pipes.

The electrical distribution system in a typical residential neighbourhood consists of one or more primary phase conductors that carry the main distribution voltage, two secondary phase conductors that carry 120 or 240 V from a step-down transformer to a number of neighbouring houses, and one or more multiple-grounded neutral conductors. In this report, the currents that flow along the phase conductors, through the residential loads, and back along the neutral conductor, will be referred to as load currents. The term grounding current will be used to refer to the currents that flow in loops formed by the neutral conductor and the multiple ground connections to earth, water mains, cable sheaths, and so on as a result of load unbalance and other factors.

For each current-carrying conductor, the magnetic field is greatest near the conductor and decreases with increasing distance. However, if the fields from several conductors come together at a given point, they may either complement or cancel each other. Therefore, in general, field prediction requires a detailed knowledge of the phase and amplitude of the current flowing in each conductor.

Given these sources, the wide variations observed in residential magnetic field levels/2/ should not be surprising. The question may then be asked; under what circumstances will the physical presence of the distribution transformer cause elevated magnetic field levels in nearby homes?

One possibility is that the transformer itself may produce a localized magnetic field that extends into the house. In fact, the magnetic field produced by distribution transformers has a very short range. It has been observed to extend as far as 3 or 4 m from the transformer in some underground systems/3/, but is probably not detectable at ground level in the majority of urban overhead systems.

A second possibility is that the secondary load current may be the major source of magnetic field. As a general rule, however, the magnetic field produced by load currents does not extend very far and is not considered to be a major contributor to fields inside homes/4/. As an example, a balanced load current of about 150 A may be required to produce a field of 0.1 μT at the front entrance of a house located 10 m (30 feet) from the distribution conductors, whereas the same field may be produced by a grounding current of about 5 A on the neutral conductor. Therefore, exceptions to the rule are likely to occur only where the load current is quite high and the grounding currents are coincidentally very low.

A third possibility is that grounding currents themselves and their resulting fields may be significantly higher near the transformer. So far, little information exists on the variation of grounding currents in relation to the position of the distribution transformer, so this possibility remains to be tested.

3. TEST SITE DESCRIPTION

The location of the planned transformer move is a low-density, single-family home, residential neighbourhood in the Toronto-Hamilton urban complex. The distribution lines, shown in Figure 1, consist of a local-area 4160-V primary and a 120/240-V secondary mounted on wood poles.

The primary circuit is 3-phase, with three No. 3/0 AWG ("large-gauge") conductors mounted horizontally on a cross-arm, and a nominal loading of 30 A. A white-phase branch extends to the west of the test area. Two No. 1/0 AWG secondary phase conductors and one No. 1/0 AWG common interconnected and multiple-grounded neutral are strung on the poles below the cross-arm with stand-off insulators. The secondary span under test extends from pole 1 to pole 4 and is supplied from the primary blue phase by a 50 kVA step-down transformer installed on pole 2. Another secondary span, going west from pole 4, is supplied from the white phase by a transformer installed on pole 5.

The secondary span under test supplies seven homes, labelled A to F in Figure 1. The residential service drops, two of which are underground, have three spun No. 1/0 or 2 AWG conductors (2 phase and 1 neutral) except for house C which appears to have two sets of No. 2/0 AWG conductors in parallel. Residential services also include cable TV (overhead on the distribution poles), telephone (underground), and a municipal water supply to which service drop neutrals are connected according to the electrical code.

A simplified schematic of the network of street conductors for this location is shown in Figure 2.

4. TEST PROCEDURE

The tests were carried out on the day of a planned move of the distribution transformer from pole 2 to pole 4. Prior to the tests, a replacement 50 kVA transformer was mounted on pole 4, but was not connected. Following an initial set of measurements, the replacement transformer was connected in parallel with the original and the original was then removed, the change being made without loss of service. A final set of measurements was then made. The total elapsed time was about 2.5 hours.

Magnetic fields were measured with an EMDEXC recording three-axis gaussmeter/5/. The meter was mounted 1 m above grade on a wheeled platform designed to produce field readings at 2 m intervals while the platform was wheeled along a designated ground-level profile. A set of measurements consisted of three longitudinal (parallel to the distribution conductors) and two transverse profiles. The longitudinal profiles were taken directly under the conductors and 10 m on each side, and extended one pole distance beyond each end of the secondary span. The transverse profiles were taken at poles 2 and 4 and extended 12 to 20 m on each side (depending on obstructions).

In addition to the field measurements, recording clip-on ammeters were installed on the common neutral conductor between poles 3 and 4, and around all three service-drop conductors for houses A, B, C, D, F, and G, for the duration of the tests. The net service-drop current should be a reliable indicator of grounding currents flowing to the residential water pipe.

5. RESULTS

The before and after longitudinal profiles are shown in Figures 3 to 5 in relation to the locations of poles 0 to 5 from Figure 1. The before and after transverse profiles are shown in figures 6 and 7, in which the short vertical lines mark the intersections with the longitudinal profiles. In addition, the average fields within 4 m of poles 2 and 4 before and after the move are shown in Figure 8. The average fields were calculated from the 16 individual measurements closest to the pole as shown in Figure 9, with the exception that a single anomalously high reading obtained at pole 2 following the move was not used. This reading was apparently influenced by being taken close to the service drop conductors which ran down the pole on their way to house C.

The recording ammeters on houses A and G failed to work correctly. The temporal variations of the neutral current and the remaining net service-drop currents are shown in Figures 10-14. Because of wide fluctuations in the neutral and grounding currents, some form of temporal averaging is required to compare before and after values. Net service-drop currents were averaged for a period of 1 hour before and 1 hour after the transformer changeover, with the results shown in Figure 15.

6. DISCUSSION OF RESULTS

The data obtained from a survey of this type are necessarily limited because of the logistical difficulty of monitoring the currents flowing in many of the conductors, and the inability to correct for temporal variations of the primary and secondary circuit loads. In addition, the distribution circuit layout may not be representative of residential neighbourhoods in general. This discussion is therefore restricted to the site under study but may provide some insight into the factors that may more generally be affected by transformer location.

The longitudinal profiles taken before the move show the highest fields, ranging from 0.4 to 0.5 μT, between pole 4 and pole 5. Magnetic fields near the secondary span between poles 1 and 4 range from 0.2 to 0.4 μT. There appears to be no evidence of significantly elevated fields near the transformer location at pole 2. The transverse profiles show the expected fall-off on either side, somewhat skewed for pole 4, with fields in the range of 0.1 to 0.2 μT at residential front-door distances.

Profiles taken after the move show essentially no change between pole 4 and pole 5. Along the secondary span, there is an increase between pole 1 and pole 2 and all along the street side, but a decrease between poles 2 and 4 on the house side. The transverse profile at pole 2 shows that, at greater distances from the line, the field is increased on both sides after the transformer is removed. The 16-point average field near pole 2 is slightly increased after the move, and the 16-point average field near pole 4 is slightly decreased, but the changes are too small to be considered significant.

House grounding currents ranged from 0 to 2.5 A before the move and from 0 to 3.7 A afterwards. For comparison with the above field values, a current of 1 A flowing through the house service entrance or water pipe will produce a magnetic field of 0.2 μT at a distance of 1 m from the conductor. Following the move, the average neutral current between pole 3 and pole 4 roughly doubled, from 5 to 10 A, and the average net service drop currents, initially in the range from 0.6 to 1.6 A, increased by 30 to 70%. These changes could be caused by the transformer move, or alternatively by changes in the primary or secondary loads. In either case, there is no clear association between the residential grounding current

increases and the transformer location. In fact, the greatest percentage increase occurred in the house farthest from the new location.

The profiles do not show any evidence of a localized increase in the street-level magnetic field close to the transformer, and thus support earlier data suggesting that the transformer itself is not a significant source of field. Similarly, they do not show a gradual increase in magnetic fields from pole 1 to pole 4, as would be expected after the move if secondary load current were the major field source. Finally, there is no clear evidence that grounding currents are highest next to the transformer. Thus, while the magnetic field distribution did change after the move, the magnetic fields at individual houses do not appear to conform to any simple hypothesis. The actual field pattern is rather more complex, suggesting multiple current sources with variable phase relations, but without any definable association between higher currents and proximity to the transformer.

7. SUGGESTIONS FOR FURTHER WORK

Two basic questions are addressed by studies of this nature. First, how does the system used to distribute electrical energy affect the electric and magnetic field environment in peoples homes? Second, what engineering features of the distribution system might cause these fields to be higher in one house than in another? The present study was designed to address these questions with particular reference to the location of the distribution transformer.

Evidence is accumulating that the magnetic field of the transformer itself, like that of most appliances, has an effective range of only a few metres. This conclusion is in agreement with predictions based on a knowledge of transformer design and is fully supported by this study. Distribution transformers will therefore not generally be a significant source of residential fields due to their physical isolation. Consequently, the cost of further studies of transformer fields beyond a distance of 2 or 3 m, probably requiring special laboratory conditions, would be hard to justify in terms of relevance to the home environment.

When comparing the residential fields from load currents and grounding currents, the relative magnitudes of the currents have to be taken into account. As indicated in an earlier section, grounding currents smaller than 5% of the load current can nevertheless provide the larger field contribution, as they appear to do in this test neighbourhood. A better understanding of the flow of grounding current should therefore be the first priority. More studies, including additional ground-level magnetic field surveys, network current measurements, and computer modelling, will be necessary in order to establish what relationship exists between grounding currents and system design parameters such as transformer location, load unbalance, and neutral grounding.

The technical difficulties of carrying out quantitative studies in the real world should not be underestimated. An urban residential neighbourhood is actually a very complex electrical network with a constantly changing electrical load, and the tracking of all significant currents can present serious instrumentational problems. In the present study, the measurements that were obtained are not sufficient to quantify or even identify the important currents with any certainty (a tendency to speculate about possible current distributions will be resisted as being beyond the scope of the present report). A developmental approach, starting with simple wiring configurations and then working towards greater complexity, is recommended for cost effectiveness. Such an approach is now being used in the Research Division's Source Characterization program/6/.

8. CONCLUSIONS

Measurements have been made of ground-level magnetic fields and house grounding currents in the vicinity of a residential distribution system before and after the relocation of a pole-mounted distribution transformer. The measurements are limited by an inability to correct for temporal variations in primary and secondary load. Within this limitation, representative field and current distributions are obtained. Magnetic fields range from 0.2 to 0.5 μT under the distribution wires and fall off to between 0.1 and 0.2 μT at residential front-door distances. House grounding currents, measured on the service drop conductors, range from 0 to about 3.8 A. For the site tested, the study does not show an association between higher residential magnetic fields and proximity to the transformer.

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5. Manufactured by Electric Field Measurements Co., W. Stockbridge, MA., U.S.A.

6. A part of the Ontario Hydro Corporate EMF Risk-Assessment Program (EMFRAP).

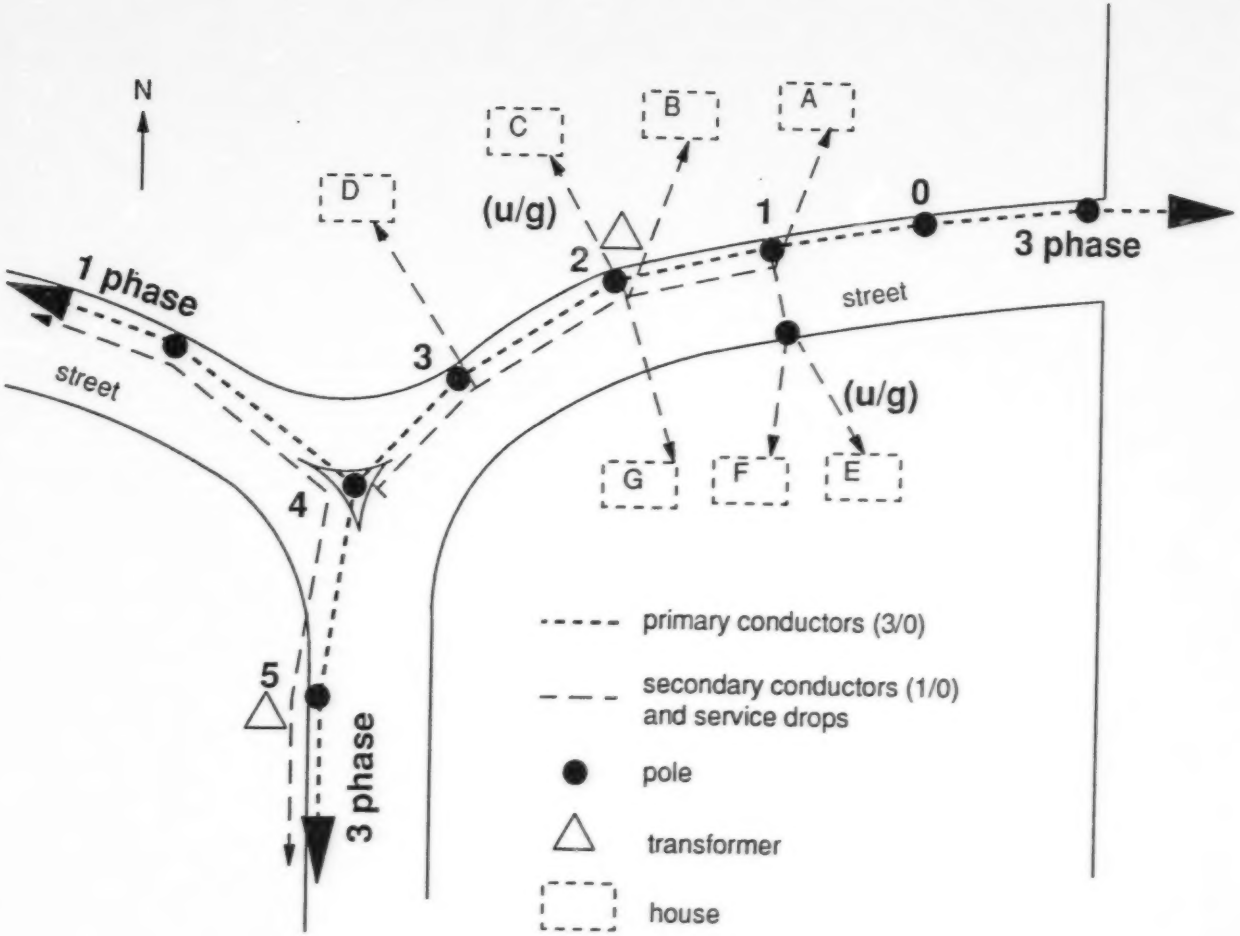

Figure 1: Arrangement of Distribution Conductors

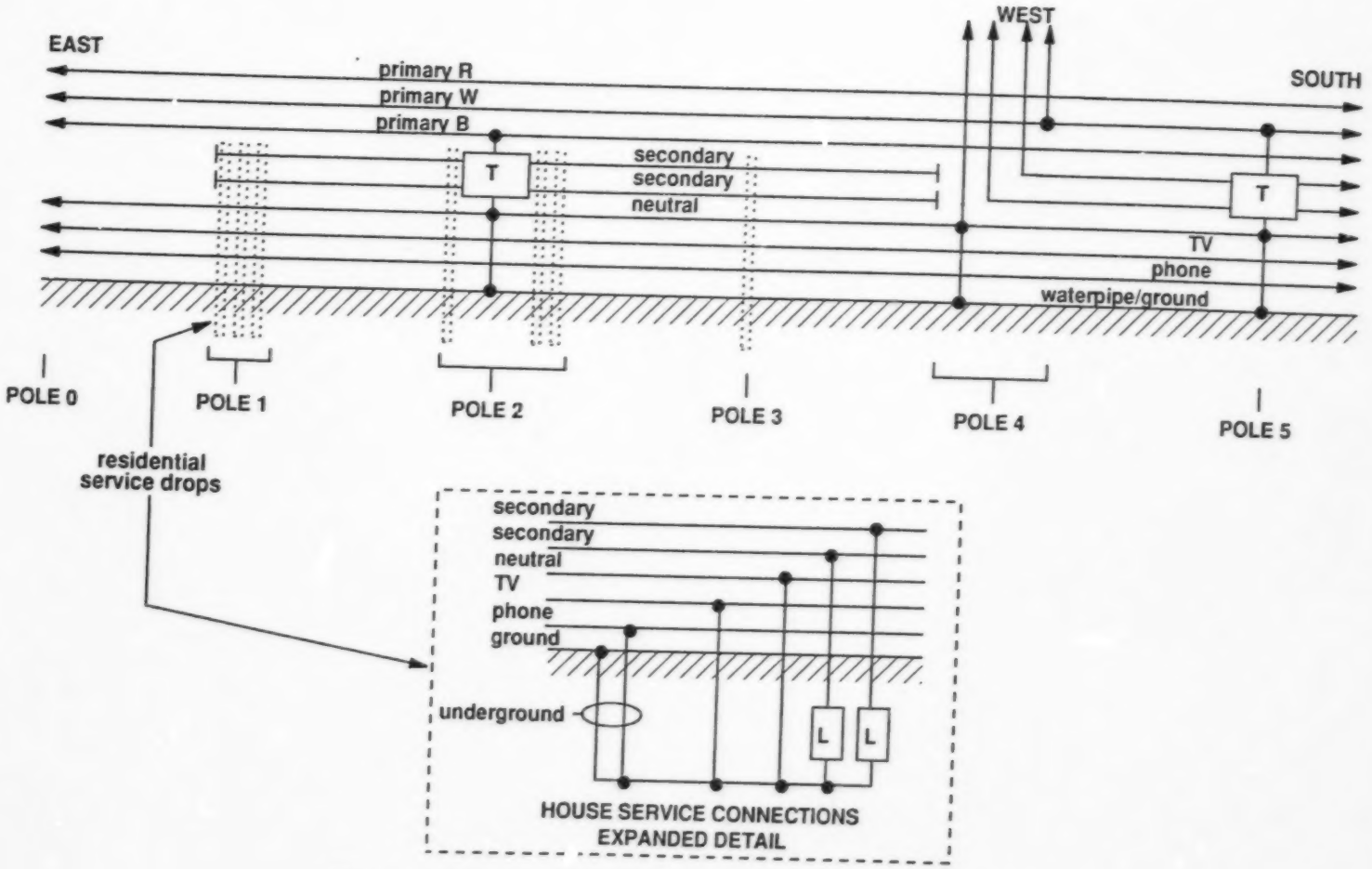

Figure 2: Simplified Schematic of Street Wiring

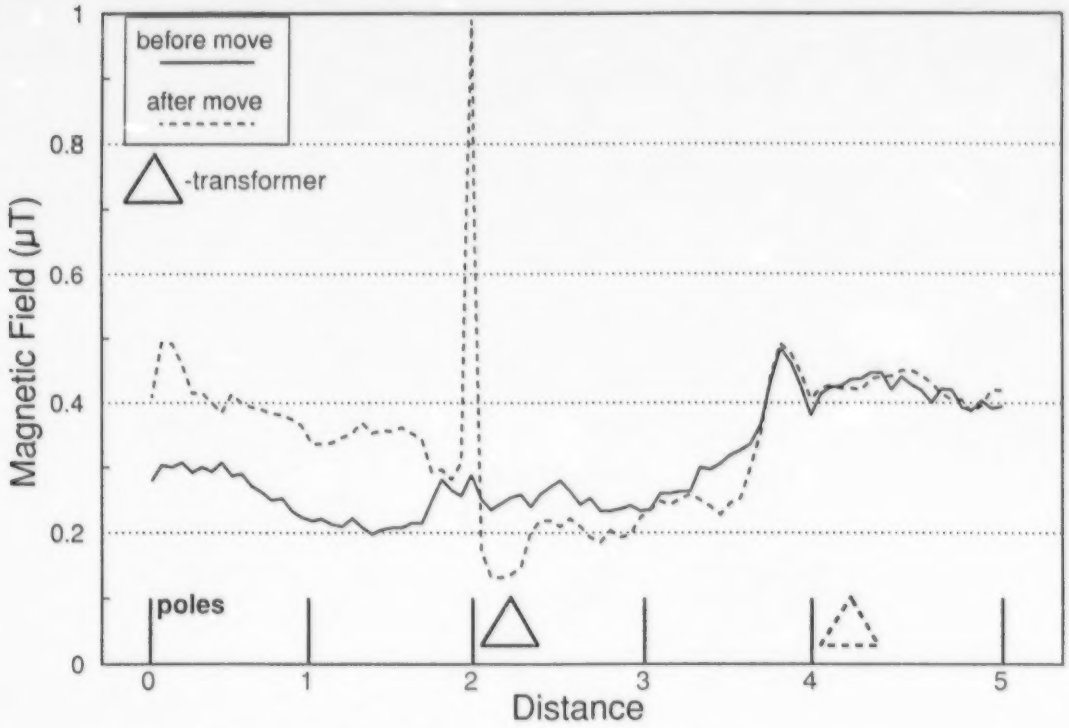

Figure 3: Longitudinal Magnetic Field Profile- underline

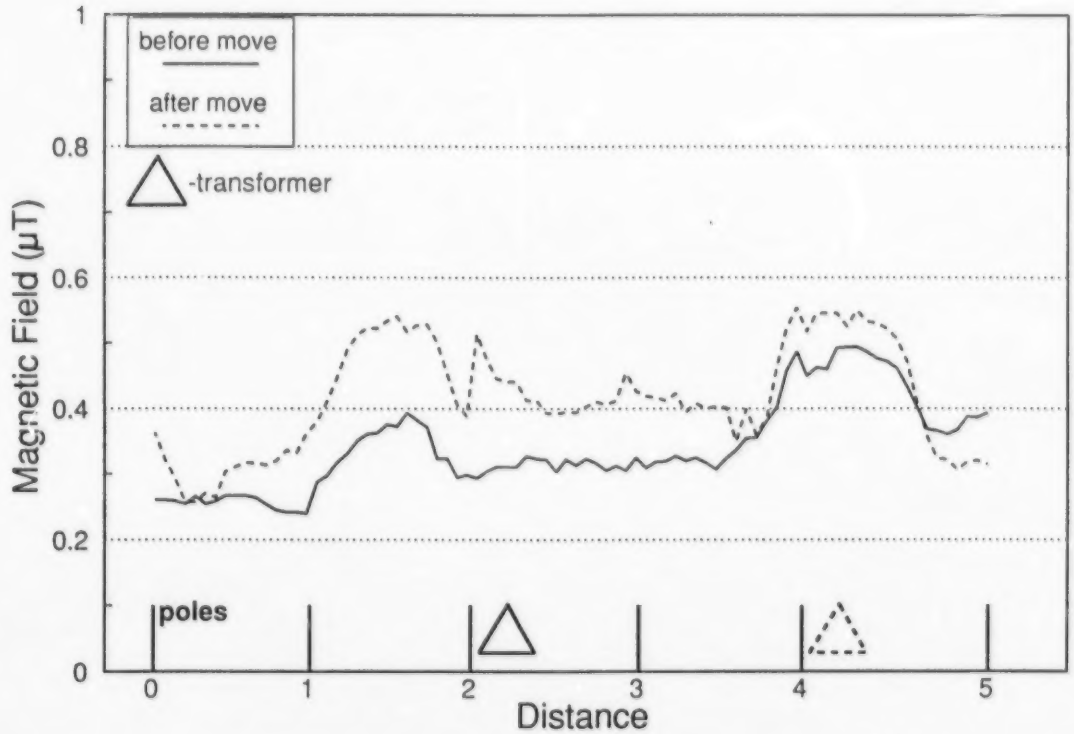

Figure 4: Longitudinal Magnetic Field Profile- street side

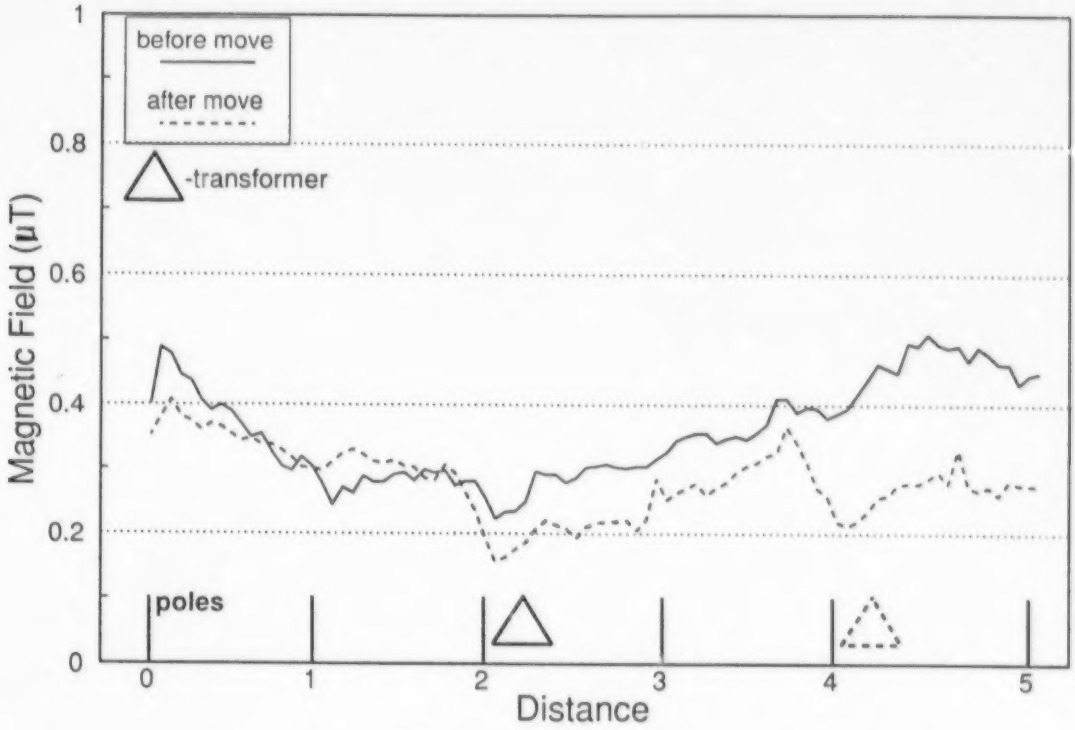

Figure 5: Longitudinal Magnetic Field Profile- house side

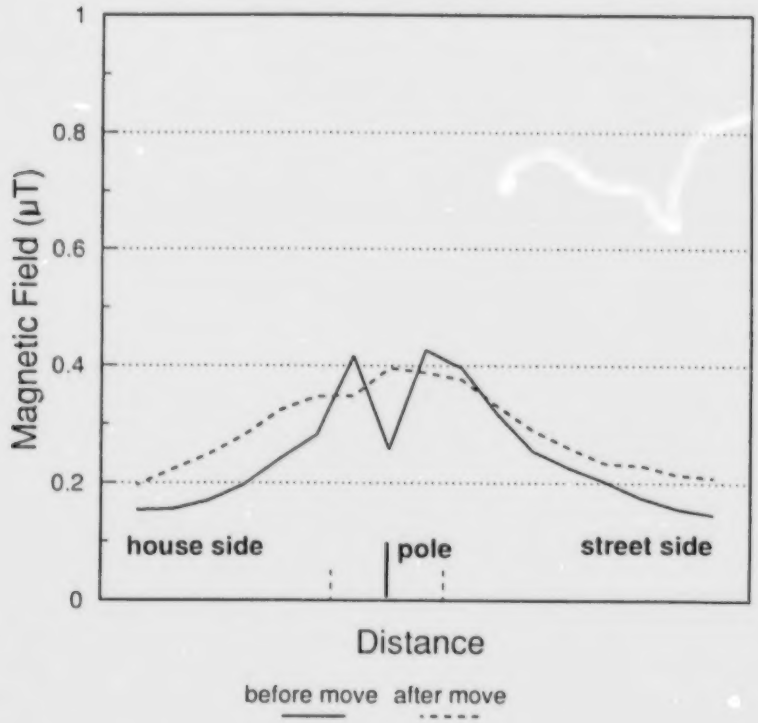

Figure 6: Transverse Magentic Field Profile- pole 2

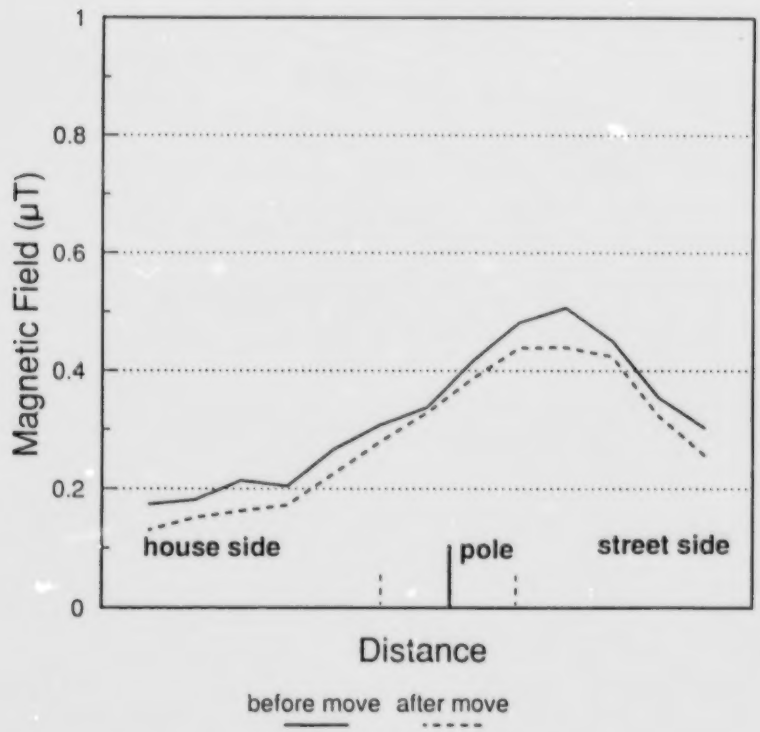

Figure 7: Transverse Magnetic Field Profile- pole 4

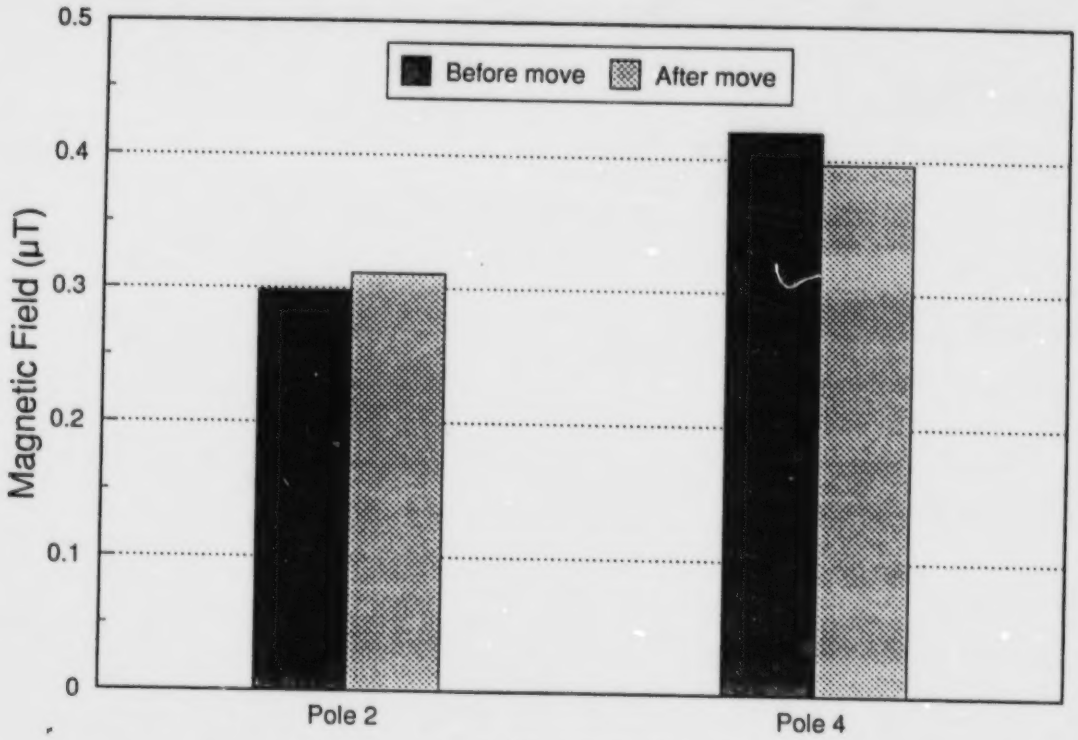

Figure 8: Average Magnetic Field Under Poles

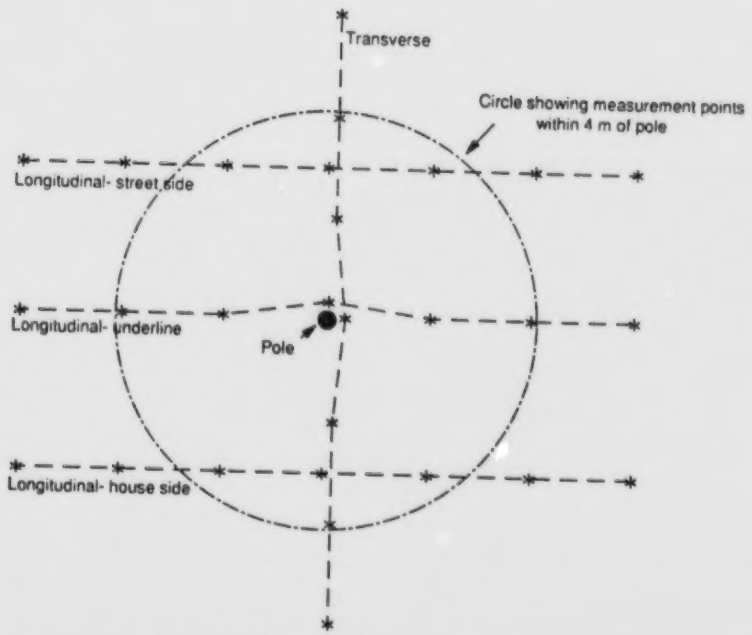

Figure 9: Nominal Relationship Between 16 Points Selected For Calculating Average Field and Pole Position

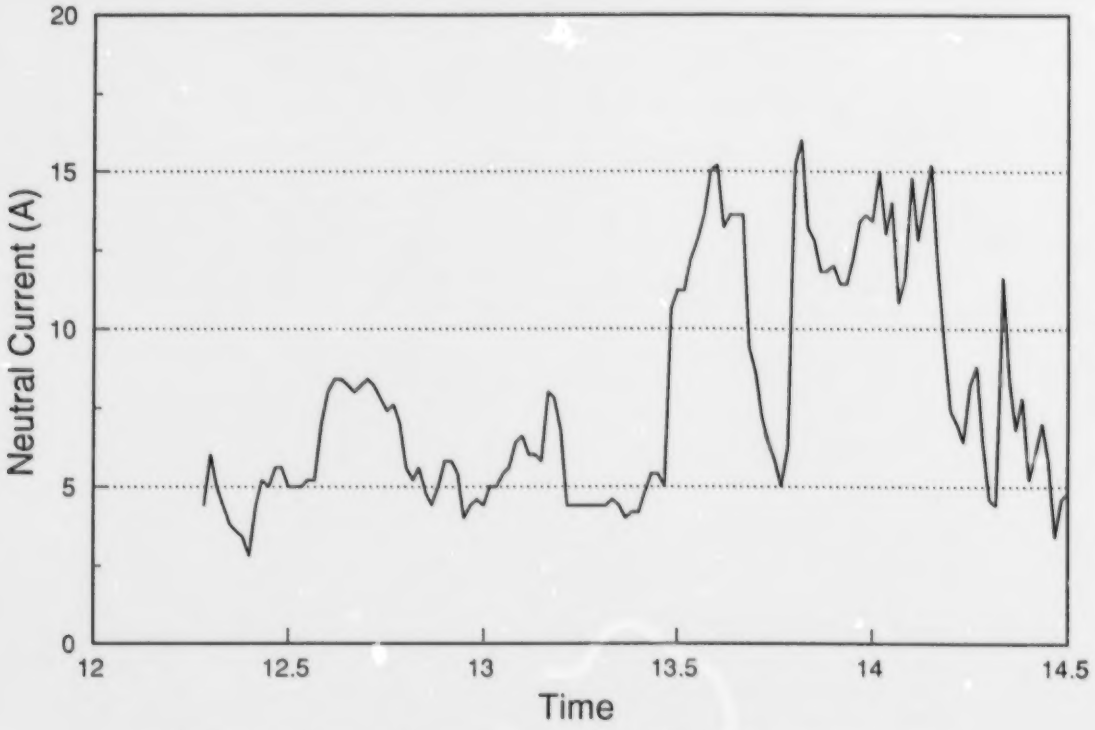

Figure 10: Neutral Current Between Pole 3 and Pole 4 vs. Time

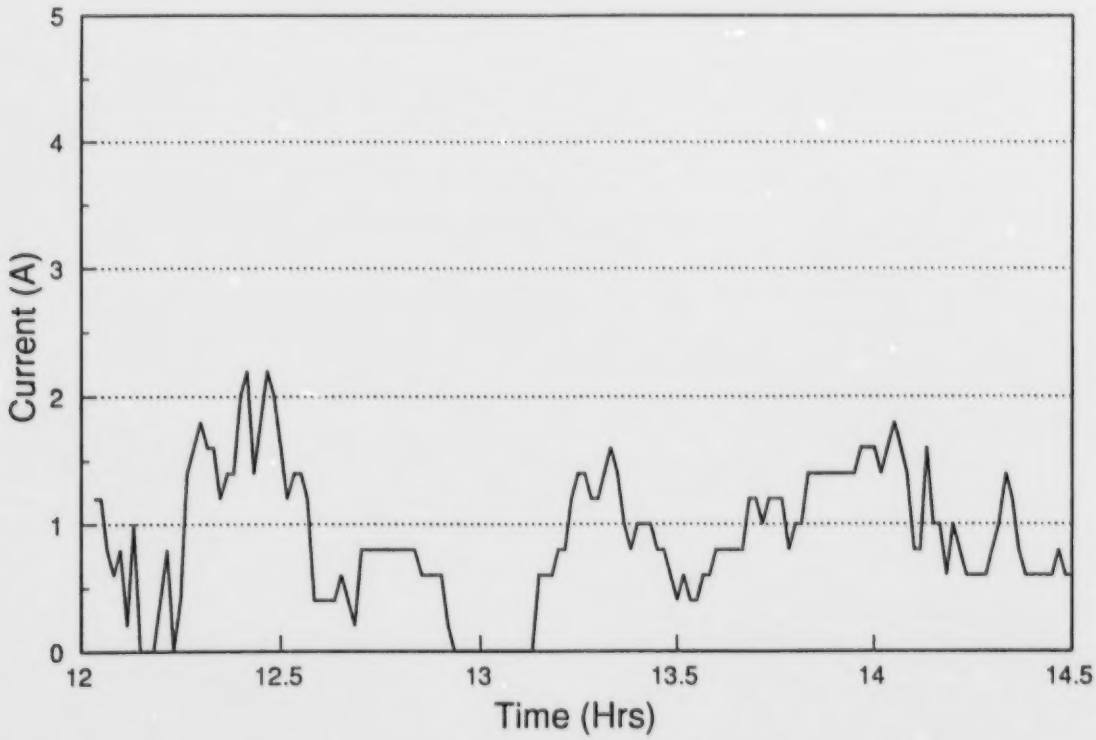

Figure 11: Net Current on Service Drop- house B

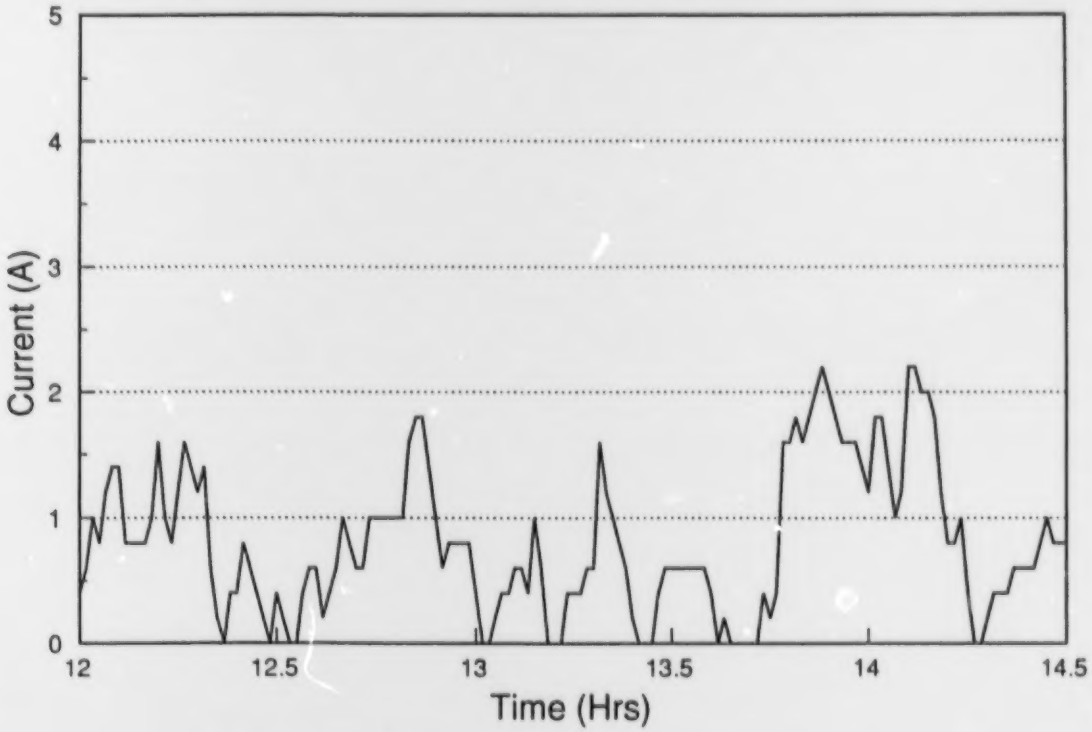

Figure 12: Net Current on Service Drop- house C

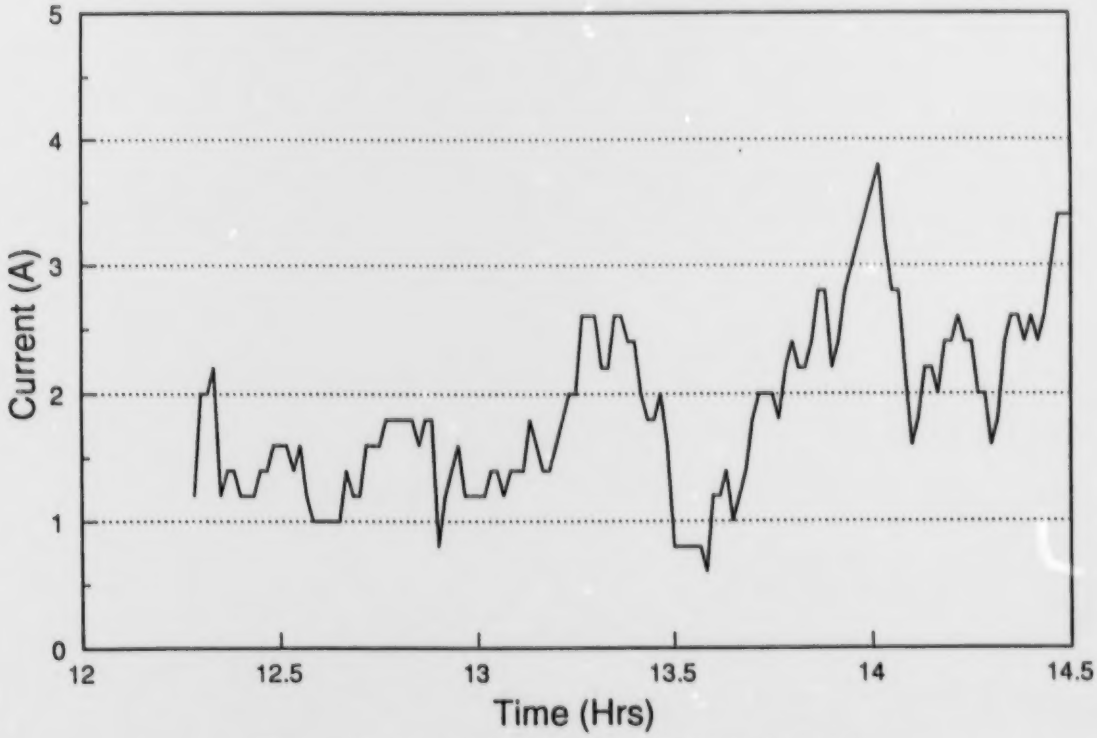

Figure 13: Net Current on Service Drop- house D

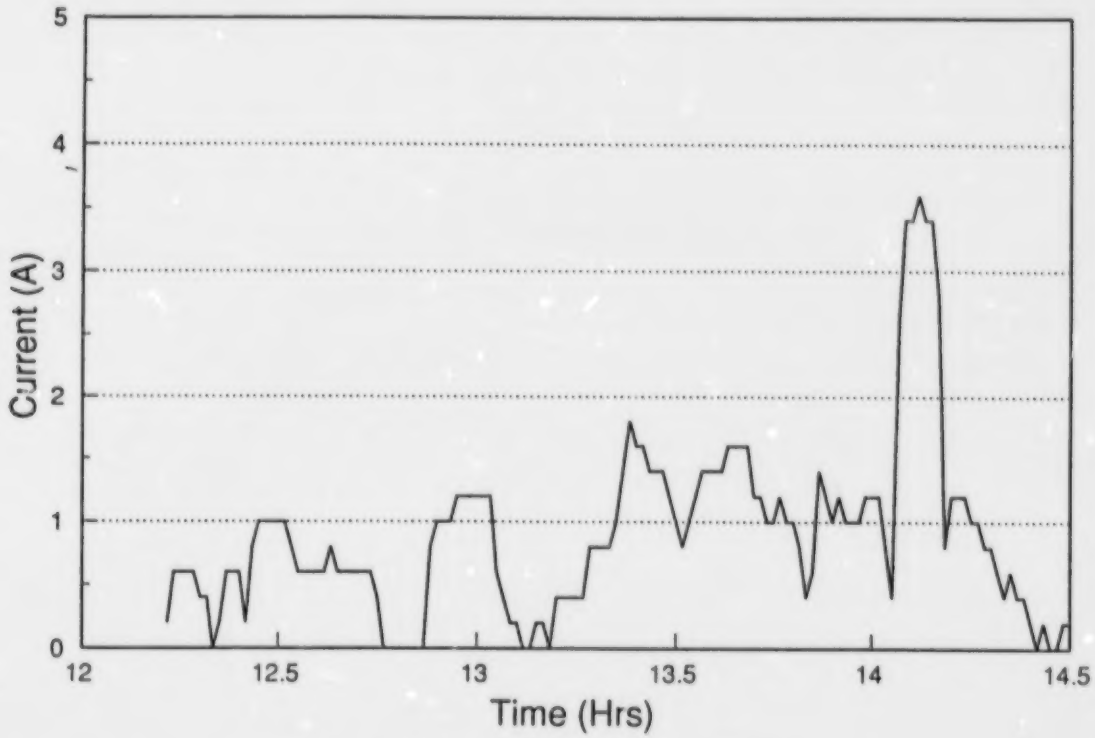

Figure 14: Net Current on Service Drop- house F

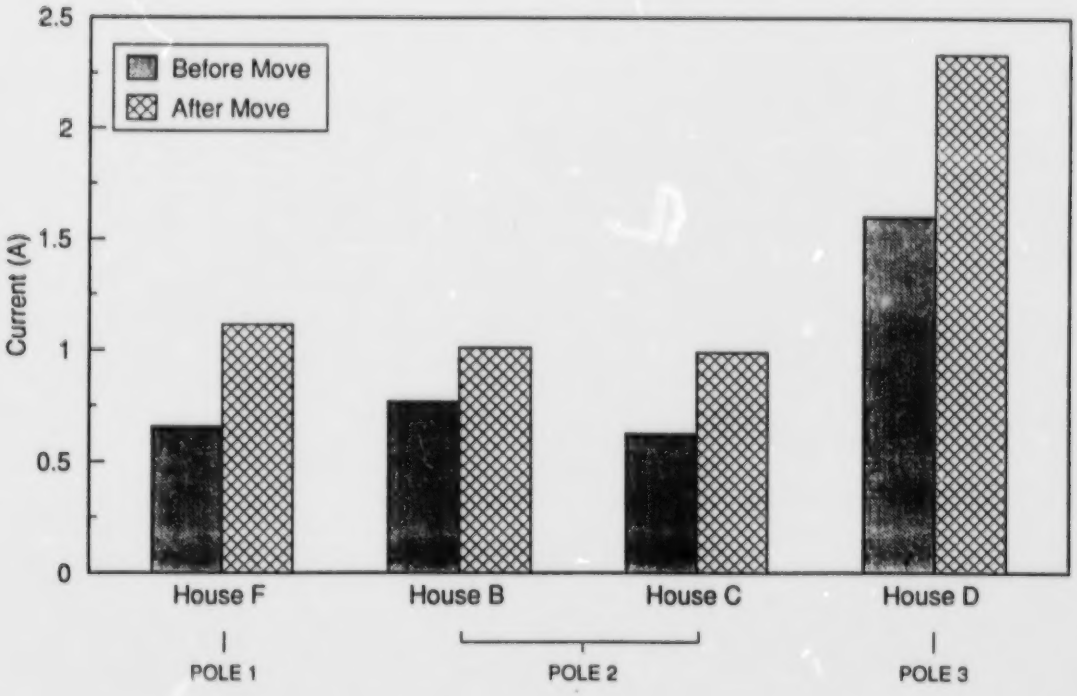

Figure 15: Net Current on Service Drops- 1 hr average